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EVALUATION OF THE DEPOSIT DURING PROSPECTING AND EXPLORATION

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PART I. ON THE CHARACTERISTICS OF MERCURY AND ANTIMONY:

THEIR APPLICATION, ECONOMICS, AND ORE TECHNOLOGY

Chapter 1. Properties of Mercury and Antimony

Mercury and antimony are metals having distinctly different properties and, consequently, completely dissimilar fields of application. Nevertheless, deposits of both these metals have a great deal in common; they are frequently formed under similar geological conditions. Moreover, in some cases, mercury and antimony are extracted from complex mercury-antimony ores.

Therefore, in examining the properties of mercury and antimony, it is important to take into consideration not only those properties which determine the direction of their practical application, but also the common conditions governing the formation of their deposits.

Table 1 gives the basic physical properties of mercury and antimony.

When heated, mercury undergoes intensive expansion which, in the range from 0° to 100° is almost proportional to the expansion of gases. Mercury is very volatile even at normal temperatures.

Thus, the pressure of mercury vapor at 20° C constitutes 0.0013 mm of the mercury column, while at 100° it reaches 0.279 mm. Mercury vapor is extremely poisonous, and prolonged exposure to it, even of low concentration, causes serious toxic effect.

In its chemical compounds mercury is monovalent or bivalent. There are numerous mercury compounds. Among these are amalgam, mercuric oxide, sulfides and sulfo salts, haloid compounds, sulfate, and nitrate.

Amalgam (alloy) of mercury is easily formed through direct diffusion in it of other metals, such as Au, Ag, Zn, Pb, Al, et al. Among oxides of mercury there are the Hg_2O oxide and the HgO oxide. Mercury sulfides are the most widely encountered mercury compounds. There are several modifications, of which 2 are the most important: red mercuric sulfide and black mercuric sulfide. The red sulfide (vermillion) is formed when it is separated from alkaline solutions, while black cinnabar (metacinnabarite) is separated from acid solutions. Mercuric sulfides are practically insoluble in water, but dissolve easily in solutions of alkali sulfides, forming with them complex compounds of the $nHgS \cdot nNa_2S$ type.

Of the haloid compounds the most important are the chlorides which have broad application in medicine: $HgCl_2$ chloride and Hg_2Cl_2 , also known as calomel.

Sulfate of mercury, $HgSO_4$, which is water-soluble only difficultly, is most probably formed in nature as a result of the action of sulfuric acid not directly on the cinnabar, but on the products of its variations -- natural mercury or red mercuric oxide (montroidite).

Nitrate of mercury, $\text{Hg}(\text{NO}_3)_2$, is an intermediate product of the formation of the industrially important, so-called mercury fulminate, $\text{C}_2\text{Hg}(\text{NO}_2)_\text{H}$.

Mercuric cyanide is an exceedingly poisonous compound, and is occasionally used in medicine. Mercury produces almost no salts of weak acids, since mercury itself is a weak base.

In its chemical compounds antimony is trivalent or pentavalent. In acid solutions, compounds of pentavalent antimony usually change to trivalent antimony, thus acting as acidifiers. Acids corresponding to the valences of antimony are Sb_2O_3 and Sb_2O_5 . Most commonly encountered in nature are the rhombic trioxide (valentinite) or cubic trioxide (sarnamontide). The combination of antimony trioxide and pentoxide yields the tetroxide Sb_2O_4 , which also occurs in nature as cervantite. Hydroxide $\text{Sb}(\text{OH})_3$ is clearly amphoteric in character, while hydroxide of pentavalent antimony is acid in character.

Haloid salts of antimony are volatile and dissociate weakly in aqueous solutions.

Of great importance are antimony sulfides and sulfo-salts. Antimony trisulfide Sb_2S_3 is the principal industrial antimony mineral. Its melting point is approximately 550° C. It is not soluble in water, but with an S^- ion, it forms a complex easily soluble ion $2(\text{SbS}_3)^{''}$. Pentavalent antimony is not found in nature. In technology it is used in the vulcanisation of rubber. In the sulfo-salt, Sb_2S_3 acts as a sulfo-anhydride, forming the so-called sulfo-antimonites.

A special group is formed by the combination of antimony with metals, viz., antimonide of sodium, nickel, and silver.

Relatively small quantities of antimony will increase the hardness of such soft metals as lead and tin.

Of the chemical properties of mercury and antimony, the most significant in the matter of explaining the formation of their deposits are the ability of their principal natural compounds, the sulfides (cinnabar and antimonite), to dissolve easily in aqueous solutions of alkali sulfides, producing complex ions of the $2(\text{SbS}_3)'''$ and the HgS_2'' type.

TABLE 1
PHYSICAL PROPERTIES OF MERCURY AND ANTIMONY

	Atomic number	Atomic weight	Specific weight	Hardness	Color	Melting point in °C	Boiling point in °C	Specific electric conductivity with respect to silver (%)
Mercury	80	200.61	13.55	Liquid at normal temperature	Silver-white	-38.7	357.25	1.58
Antimony	51	121.76	6.67	3 (Mohs scale), brittle	Lead-white	630.5	1325 (approx.)	3.76

Chapter 2. Application of Mercury and Antimony and the Economics of These Metals

In view of the variety and types of applications of mercury and antimony in the most important branches of industry, both these metals are considered strategic raw materials.

Application and Economics of Mercury

In metal form and in combination, mercury is used in medicine, the chemical industry, the electric power industry, instrument building, agriculture, mining, the manufacture of felt, etc.

In the basic chemical industry, sulfate of mercury is used as a catalytic agent in the production of acetaldehyde from acetylide. In the electrolysis of sodium chloride for the purpose of obtaining chlorine and sodium hydroxide, mercury cathodes are currently used that make it possible to obtain sodium hydroxide of great purity. Mercury is also indispensable in the manufacture of certain paints used to cover the underwater portion of vessels.

Mercury fulminate is widely used as a detonator in explosive operations in the field of mining. Mercury rectifiers, quartz mercury vapor lamps, thermometers, manometers, diffusion vacuum pumps, and numerous measuring instruments and control apparatus would be unthinkable without the use of mercury. In agriculture compounds containing mercury are used as mordant for seed. In the field of medicine, mercury has for many years been used in the form of mercuric chloride, calomel, as the principal component of various ointments, mercuric-organic compounds, dental amalgams, and in many other medications.

More and more attention is being devoted to the use of mercury in the field of power, in mercury vapor boilers and turbines. In that regard it was found useful to combine mercury and hydraulic installations which utilize the heat of mercury vapor condensation. In such binary, mercury-hydraulic power installations it has been possible to increase efficiency some 38 to 45%, while decreasing fuel consumption almost by $\frac{1}{2}$ of the fuel used with water boilers.

Table 2 contains official average annual figures of mercury consumption in the United States during the period 1946 to 1950:

TABLE 2

ANNUAL CONSUMPTION OF MERCURY IN THE UNITED STATES, 1946-1950

Area of utilization	Quantity of mercury used	
	(t)	(%)
Basic chemistry (production of chlorine and sodium chloride)	28.4*	2.8
Agriculture and forestry	174.0	17.1
Electrical apparatus	254.2	25.1
Precision instruments	180.0	17.9
Pharmaceuticals	137.0	13.6
Catalytic agents (production of vinegar, etc.)	116.7	11.6
Antifouling paints for vessels	52.0	5.1
Dental medicine	36.7	3.5
Mercury fulminate	14.4	1.4
Laboratories	14.5	1.4
Amalgams	5.1	0.5
	1,013.0	100.0

(*) In the production of chlorine and sodium chloride, mercury is used only in the loading of the electrolytic bath; it then regenerates itself in the course of the operation.

It should be noted that the United States expended increased quantities of mercury during the war -- up to 1,880 t in 1943, primarily in the production of disinfectants for the army (total quantity of mercury used in the manufacture of pharmaceuticals reached 503 t at that time), and for explosives (108 t).

Based on available data concerning mercury deposits in Europe and America, from the year 1500 through 1950 about 670,000 t of mercury were obtained; of this total annual production in the 20th century averaged from 4 to 4.5 thousand t.

More than 70% of all mercury was obtained in the following 5 deposits: Almaden (Spain), 206,000 t; Idriya (Yugoslavia), more than 90,000 t; New Almaden (US), 60,000 t; Juankavelika (Peru), 55,000 t; and the Tuscany deposit (Italy), nearly 40,000 t.

Maximum production of mercury in the foreign countries was achieved in 1941, with a yield of more than 9,500 t. Furthermore, particularly in the twentieth century, a very large number of small deposits were under exploitation, with a total annual production of not more than 10 to 15 thousand t. Thus, in the United States in 1942, some 184 mines yielded but 1753 t of mercury.

The data presented in Table 3 will illustrate the quantities of mercury produced in various foreign countries in recent years.

A comparatively sharp change in mercury production totals for the different years can be explained, primarily, by the fluctuation in the price of mercury. The increase in the price of mercury during the war or during the preparation for war is followed by a marked increase in mercury production and, conversely, the drop in price during periods of economic crisis causes marked reductions in the production and complete stoppage of production in certain countries. It is also significant that the great demand for mercury during World War II, when Spanish and Italian mercury was in the hands of the Germans, resulted in the organization of production in other countries, such as Canada, Mexico, Asia, and South America.

Mercury prices in the world market are usually quoted in dollars per cylinder, which is the accepted international unit for mercury. The quantity of mercury per cylinder is strictly standardized. Up to 1927 a cylinder held 34.05 kg, while beginning in 1928,

PRODUCTION IN FOREIGN COUNTRIES (IN t, (ND - NO DATA)

Country	1923	1928	1938	1943	1947	1950
Asia						
China	120	68	2	118	--	ND
Japan	--	--	25	231	--	45
Turkey	--	--	20.5	6	ND	ND
Europe						
Spain	1,245	2,195	1,379	1,646	1,858	1,745
Italy	1,004	1,984	2,301	2,137	ND	1,839
Austria	820	5	--	ND	ND	ND
Czechoslovakia	--	72	100	ND	ND	ND
Germany	--	--	60	ND	ND	ND
North America						
Canada	--	--	--	768	ND	ND
USA	687	616	620	1,790	799	156
Mexico	166	45	155	294	976	126
South America						
Peru	--	--	--	11.2	ND	ND
Bolivia	--	--	--	95	ND	ND
Chile	--	--	--	95	ND	ND
Africa						
Algiers	--	--	--	2	ND	ND
Tunis	--	--	--	18	ND	ND
Union of South Africa	--	--	--	41	ND	ND
Australia and New Zealand	--	--	0.3	3	ND	ND

(Note: Based on a survey by Minerals Industry, over-all production of mercury in 1943 was approximately 8,150 t, as against 4,800 t in 1950.)

a cylinder was standardised at 34.5 kg. In Table 4 mercury prices are listed in dollars per ton, to facilitate comparison with prices of antimony and other metals.

TABLE 4
MERCURY PRICES (NEW YORK STOCK EXCHANGE)

Year	Price
1913	1,158
1928	3,630
1938	2,180
1943	5,660
1950	2,350

It must also be noted that during industrial utilization of mercury the price remains almost unreduced, and the production of secondary mercury, contrary to antimony, has almost no industrial significance.

Application and Economics of Antimony

By far the greatest quantities of antimony are used in industry to form alloys with other soft metals. This process takes advantage of the property of antimony to increase the hardness of metals. Among the more important alloys containing antimony are: antimonial lead of increased hardness, used particularly in the production of shrapnel balls; various antifriction bearing alloys having an antimony content of from 7 to 20% (babbitt); type metal (containing 15 to 25% antimony); battery metal consisting of an alloy of particularly pure lead, alloyed with a small quantity of antimony of great purity; the so-called Britannia metal which contains, in addition to tin and a small quantity of copper, 8% antimony.

Antimony compounds also have various applications. Antimony sulfide (Sb_2S_3) is used in the striking surface of matchboxes (20% Sb_2S_3 and 80% additive); antimony sulfide is also added in small quantities to artillery shells, to insure accuracy of the shells in flight. Pentasulfide of antimony is also used in the vulcanization of rubber (red rubber).

Trioxide of antimony is used in the manufacture of paint, lacquer, particularly of fire-resistant paints used on glass, ceramics, and in the manufacture of enamels. Trichloride of antimony is used in medicine as an irritant; it is also used in the burnishing of steel, particularly of armament steel. Pentachloride of antimony has the ability to give off a part of its chlorine to certain organic compounds, and it is therefore used in industrial organic chemistry as a chlorinating agent.

Antimonate of lead is a fire-resistant paint known as Neapolitan yellow. Sulfatrifluoroantimonate of ammonium is a mordant used in the dyeing of fabric. Certain antimony compounds are used in making fabric fire-resistant.

A number of organic antimony compounds, such as tartar emetic and stibosan, are widely used in medicine.

Table 5 contains official data of average annual consumption of antimony in the United States for different purposes in the years 1945 to 1950.

No accurate information is available on the quantities of antimony produced. Antimony and its minerals have been known since ancient times; however, the industrial utilization of antimony in notable quantities has begun only recently in the second half of the nineteenth century. In the past 100 years probably not more than 2 million t of antimony have been mined.

Details on antimony mining in different countries are presented in Table 6.

Based on information published by Minerals Industry, over-all production of antimony in 1948 amounted to approximately 45,000 t, reaching a total of 50,000 t in 1950.

Table 6 indicates that up to the 1930s China was the principal supplier of antimony, delivering about 2/3 of world production. The relatively low level of production in other countries can be explained by the fact that there was little interest in the study of antimony extraction when low-cost Chinese antimony was amply available on the market. However, when the intervention of imperialist Japan seriously reduced Chinese antimony production, a noted increase in antimony production could be seen in other countries, particularly in Mexico and Bolivia. Comparatively large quantities were produced in the United States.

Among the European countries, Yugoslavia has the greatest potential, with an annual production in 1940 of 4,800 t. As a result of the intensive development of the antimony industry in other countries, the world's largest annual antimony production output was reached in 1942 almost without the inclusion of China which has the largest and richest antimony deposits.

An important role in the antimony industry is played by production of the so-called secondary metal, regenerated from various byproducts. Thus the United States covers from 40 to 50% of its requirements by using the secondary metal. During World War II the United States produced 11,400 t of the secondary metal in 1940, 15,000 to 18,000 in 1942 to 1945.

The largest user of antimony is the United States which from 1942 to 1945 used from 19,500 to 25,800 t of antimony. In 1949 the United States used a total of 10,500 t of antimony.

TABLE 5

ANNUAL CONSUMPTION OF ANTIMONY IN THE UNITED STATES

Metal Production	Quantity of Antimony	
	t	%
Hard (antimony) lead, including battery metal	5,280	34.1
Bearing alloys	2,067	13.4
Type metal	1,016	6.6
Sheet and tube lead	244	1.6
Solder	151	1.0
Other	343	2.1
Total metal production	9,101	58.8
Nonmetal Production		
Fireproof fabric	1,370	9.0
Paint and lacquer	1,279	8.4
Glass, enamel, and ceramics	1,652	10.8
Other (matches, resins, antimony trichloride, plastics, etc.)	2,062	13.0
Total nonmetal production	6,363	41.2
Grand total	15,464	100.0

TABLE 6

ANTIMONY PRODUCTION IN FOREIGN COUNTRIES (IN 1,000 t)

Country	1913	1923	1928	1933	1938	1943	1948	1950
Asia -- total	13.3	15.0	23.1	14.1	8.7	1.9	4.4	1.97
China	13.0	14.6	23.0	23.7	8.0	0.4	3.3	ND
Japan	--	--	--	--	--	0.6	0.1	0.2
Burma	--	--	--	--	0.1	0.8	0.1	ND
Turkey	--	--	--	--	0.1	0.8	0.1	ND
Europe -- total	7.0	2.6	3.1	2.1	5.4	4.2	5.4	5.0
Greece	--	0.1	0.1	--	--	ND	ND	1.5
Italy	0.4	0.4	0.3	0.3	0.9	0.5	0.5	0.4
France	4.5	0.9	1.2	0.4	--	1.3	0.3	0.3
Spain	--	--	--	--	--	0.2	0.3	0.4
North America -- total	0.9	0.5	3.6	2.5	8.7	17.8	13.4	8.4
United States	--	--	--	0.5	0.6	4.6	5.9	2.3
Mexico	0.9	0.5	3.6	2.0	8.6	12.6	7.4	5.9
South America -- total	--	0.3	3.7	1.9	10.3	19.1	14.0	ND
Bolivia	--	0.3	3.5	1.9	9.4	16.5	12.3	ND
Peru	--	--	0.2	--	0.7	2.5	1.8	ND
Africa -- total	0.2	0.6	--	0.3	1.4	3.3	6.1	10.5
Algeria	0.2	0.6	--	0.1	1.0	0.9	0.8	1.5
French Morocco	--	--	--	--	0.1	0.4	0.9	0.7
Union of South Africa	--	--	--	--	--	1.6	4.1	8.3
Australia and New Zealand	1.3	0.5	0.1	--	0.6	0.5	0.2	0.2

Current annual antimony requirements of France are estimated at 4,000 t. Britain used 5,700 t of antimony in 1946, and 10,900 t in 1947, including 3,000 t of secondary antimony. In 1948, Britain increased its antimony consumption to 12,300 t.

Price of antimony on the world market is normally expressed in cents per pound. To facilitate comparison of antimony prices with those of mercury and other metals, Table 7 lists antimony prices in dollars per ton.

TABLE 7
ANTIMONY PRICES

Year	Price
1913	165
1923	173
1928	226
1933	143
1938	330
1943	362
1950	614

Naturally, the mercury and antimony resources of foreign countries are of great interest. However, no detailed information is available.

No long-range exploratory activities are being carried on in the capitalist countries. Thus, the complexity of mercury deposits led American geologists to believe that exploration for the purpose of determining available reserves is not possible. Therefore, the American mercury industry does not prepare reserves of ore deposits for exploitation.

American geologists evaluate pessimistically the mercury and antimony resources of their country. They consider that US mercury resources have been 95% depleted and that domestic mercury resources will be completely depleted in 3 years, while antimony reserves will be used up in 4 years.

China, which had the world's richest antimony resources in 1941, carried out a long-range evaluation of its resources. Based on published data, the reserves of deposits in Hunan Province contain 1,415,000 t of antimony, while total reserves in all known antimony deposits in China amount to approximately 2,500,000 t. Thus, with current world production of 30,000 to 40,000 t per year, known antimony deposits in China alone could cover world requirements for the next 60 to 80 years. As for mercury, the situation is even more favorable in view of the rich deposits in Almaden, Idriya, and Tuscany.

Below are figures comparing mercury and antimony production with that of other ferrous and nonferrous metals in 1941 (in t):

Copper	2,550,000	Nickel	136,000
Lead	1,850,000	Antimony	44,400
Zinc	1,750,000	Mercury	9,500
Aluminum	1,045,000	Silver	8,550
Tin	237,000	Gold	1,290

In conclusion it is to be noted that, prior to the Great October Revolution, there was in operation only one mercury mine, the Nikitovsk Mine in the Don Basin region. The mine operated irregularly and during its most productive years did not exceed an annual production of 300 t. There was no antimony production of any kind. Thus, Russia's requirements were covered by imports.

Exported in 1973 ... metallic mercury and some 38 t of various mercury compounds, making a total of 207 t. During the same year, 2,055 t of antimony were imported.

Chapter 3. Industrial Types and Varieties of Mercury and Antimony

Ore Industrial Types of Ore

Industrial types of ore, naturally, are classified by those properties which determine their use and technological treatment. On that basis, the simple ores whose primary component is mercury or antimony, and the complex ores in which mercury or antimony may be the prime or secondary component, must be mentioned. Further subclassifications of industrial ore types are made on the basis of mineral composition.

It must be noted that such a system of classifying industrial ore types is logical not only from the point of view of technology, but also for practical geological reasons, since this system enables geologists to search for certain deposits under specific geological conditions.

The following industrial types of ore can be listed with regard to mercury:

I. Natural mercury ore. The primary mineral contained in these ores is cinnabar; in certain cases, quantities of metacinnabarite, mercury selenide, as well as natural mercury, are contained in the ores. Ore of this type is most commonly found, particularly in the well-known ore deposits of Almaden, Idriya, Monte Amiata, et al.

II. Among complex mercury ores are the following:

(a) Mercury-antimony ores which in turn can be classified into cinnabarantimonites and livingstonites. Generally, antimonite is most commonly found in small quantities as an admixture of mercury ores; however, quantities that are of any interest at all are rarely found in mercury deposits. This is probably due to the fact that the technology of processing complex mercury-antimony ores is itself a complex process, and therefore the presence of antimonite in mercury ore has simply been ignored abroad.

The only known industrial deposit having livingstonite ore is the Giyutsuko deposit in Mexico. Until recently that deposit was looked upon as a mercury mine only; the mining of antimony was neglected until 1937 because of the complexity of the technological process involved. For this reason only some 2,500 t of mercury and 738 t of antimony were mined there between 1869 and 1943. At the present time the mine is looked upon as an antimony deposit.

(b) Mercury-arsenic ores are encountered quite frequently; their minerals consist of cinnabar and realgar with orpiment (yellow arsenic) or mercury-containing realgar. In these ores it is difficult to detect the cinnabar because of the realgar which looks very much like it. Since arsenic sulfides are sublimated at temperatures which are necessary for the pyrometallurgy of mercury, the technology of these ores is very complex indeed.

(c) In certain polymetallic and tin ores small quantities of mercury are found. Another fact worth noting is that in Sardinia several hundred kilograms of mercury have been obtained annually from dust resulting from the processing of tin ores.

Industrial types of antimony ores are varied:

I. Natural antimony ores. In all deposits of this type of ore the minerals appear as antimonites and as products of antimony oxidation. Ores in the well-known deposits such as the antimony deposits of China, Mexico, and the USSR is of that type. A large portion of total world antimony production is mined in such deposits.

II. Among complex antimony ores the following must be noted, in addition to the mercury-antimony ores mentioned earlier:

(a) Lead-antimony ores whose primary minerals, such as Jamesonite, Boulangerite, and others, are common admixtures of ores in polymetallic deposits. However, it is practically impossible to separate antimony from lead in the course of processing this ore; thus, the end product of this process is antimonous lead. This product is of great importance, since very large quantities of antimony are used in producing lead alloys. In the United States the production of alloys containing antimony resulted in large quantities of antimonous lead with a 5 to 7% antimony content. For example, in 1944, 4,670 t of antimony were obtained from such a product. Japan similarly utilized available polymetallic ores containing from 1 to 1.5% antimony.

In addition to the lead ore deposits mentioned which contain fahlers as an admixture, a number of natural fahlers ores are known. Up to now, little attention has been paid to the processing of such ores.

(b) An important group is made up of complex gold-antimony ores. These include, primarily, the Bolivian quartz-antimony veins, containing a high concentration of antimony and having a gold content of 1.5 to 8 g/t. Until recently, little attention has been paid to gold-quartz veins with antimonite. Thus, for example, gold has been extracted for many years from the quartz veins in the Murchison Ridge in Northern Transvaal, while antimony was ignored. Only after 1940 was antimony extraction begun. As a result, it appeared in 1946 that ore was extracted which contained antimony whose cost was 4 times that of the gold content in the ore. A similar case occurred at the Guadalupe mine in Cuba which, in 1920, was considered a gold mine and which in 1939 became an antimony mine. Significant quantities of antimony were obtained from gold-ore deposits in Australia and Alaska.

(c) The comparatively rare but unusual antimony-wolfram ores in which antimonite is usually associated with ferberite. These ores frequently also contain gold. Ore of this type is found in the deposits of Bolivia and also in certain deposits in the Caucasus.

Mention must be made of the unique antimony-scheelite deposit of Yellow Pine in Idaho, USA. Its ore contains 2.5% wolfram trioxide, 3.5% antimony, 51 g/t silver, and 2.5 g/t gold.

(d) Of interest are also the antimony-nickel ores in the Turkhal deposit in Turkey. Ore found there contains up to 2.8% nickel in the form of garnierite. The ore also contains such primary antimony and nickel minerals as gudmundite (FeSbS) and bravoite (FeNiS).

Ore Varieties

There are no standard varieties of mercury and antimony ore. Different varieties of ore occur in the various deposits, with every variety having specific characteristics that determine the method of processing which must be employed.

In natural mercury deposits, the different varieties are classified by the amount of mercury content, since the process of burning the ore for the purpose of precipitating the mercury differs for the various ores with different mercury content. Certain quantities of high-grade ore, with a mercury content of 1 to 2% are processed separately in retort furnaces, while the poorer grades of ore are processed in continuously rotating furnaces. While that can be done by the smaller enterprises, the larger mining enterprises do not maintain such a system of ore classification, since the mixing of the ores from a large number of stopes assures a satisfactory flow of ore of sufficiently constant mercury content.

Of great significance is the classification of mercury ores on the basis of admixture content, such as siliceous ore, carbonaceous ore, etc. This is important, because the processing of carbonaceous ore, for example, can be done with the aid of the so-called forced burning process, assuring furnace efficiency 2 to 4 times higher than would be the case with siliceous ores.

In the case of the more complex mercury ores, the classification of the different varieties of ore depends on the content of certain components. For example, in mercury-antimony deposits it is useful to identify those having a high antimony content and those with low antimony content. The former may be sent directly to the furnaces for the preliminary precipitation of mercury.

The cinders are then transferred to the metallurgy plant for extraction of antimony. The low content or poor ore, containing little or no antimony, must first undergo a mechanical concentration process. Only after the collective antimony-mercury concentrates have been formed in this manner can they be forwarded for metallurgical processing.

Ore varieties in the different antimony deposits are also classified in a similar manner. However, in the case of antimony ore the identification of the high-grade ore is even more important, since as a result of manual picking and sorting of the ore concentrates having an antimony content of no less than 30% can be obtained. Such concentrates can be directly utilized in certain branches of industry, such as the match manufacturing industry, or can be used for liquation (the smelting) of trisulfide of antimony to obtain the so-called crudum.

In antimony deposits it is extremely important to take into consideration the oxidation and mixing of sulfide-oxidized ores. This is necessary because the oxidized antimony minerals, in the course of concentration, easily become pulverized, which makes it more difficult to extract them by gravitational means; further, they cannot easily be floated. For these reasons the poor oxidized antimony ores at the present time are almost without practical value. However, oxidized antimony ores having an antimony content of not less than 3 to 5 percent can be subjected to sublimation (distillation burning); the end product of this process is trioxide of antimony. High grade oxidized ores, with an antimony content of more than 10 or 12 percent can be subjected to smelting without concentration.

In complex antimony ores it is frequently possible to identify ore varieties on the basis of certain admixture components. This is possible because in deposits of this nature the contours of industrial ores having varying components coincide only partially. Thus in the above-mentioned wolfram-antimony-gold deposits at Yellow-Pine the following ores were obtained: gold ore, with a gold content of 2.4 to 6 g/t; antimony-gold ore, with an average content of 1.5% of antimony and 2.75 g/t of gold; and wolfram-antimony-gold-silver ore, having a content of 2.5% of trioxide of wolfram, 3.5% of antimony, 51 g/t of silver, and 2.05 g/t of gold.

Finally, mercury and antimony ores must also be classified in accordance with harmful admixtures, e. g., arsenic, various organic compounds, etc. All these may make processing more difficult or may affect the quality of the product obtained. Determination of the varieties is made by means of laboratory experiments.

In the Soviet Union the quality of metallic mercury is regulated by OST T&M 33-40. Three separate qualities of mercury are identified; their characteristic properties and data are presented in Table 8.

TABLE 8

VARIETIES OF MERCURY (IN ACCORDANCE WITH GOST)

Brand	Chemical composition in %		Designation
	Mercury, not less than	Nonvolatile residue, not more than	
R1	99.999	0.001	Vacuum electroengineering
R2	99.990	0.010	Control and measuring instruments
R3	99.900	0.100	Amalgamation of gold; preparation of salts and pharmaceuticals

Additional requirements are that mercury of whatever kind be silver-white in color, have a mirrorlike surface, and be free of mechanical admixtures (sand, soot, etc). Mercury of brand R1 and R2, when shaken, must not stick to the sides of a clean glass jar. Nor must mercury of these 2 brands leave any traces on smooth white paper or on a marble slab. Mercury of all brands must be fully soluble in nitric acid having a specific weight of 1.2.

Chinese antimony dominated the world market for a long time. The only quality requirement was that it contain not less than 99% antimony and not more than 0.3% arsenic. Chinese antimony was refined in England. Products made by English firms contained 99.6 to 98.9% antimony, had an admixture of 0.1 to 0.7% lead, and contained 0.09 to 0.2% arsenic, as well as other metals in very small quantities.

In the Soviet Union production of antimony is governed by GOST 1089-41. Based on chemical composition, 5 varieties of metallic antimony are recognized. Specific data are given in Table 9.

TABLE 9

VARIETIES OF ANTIMONY (IN ACCORDANCE WITH GOST)

Brand	Antimony and lead, not less than	Of that, lead not more than	Copper	Arsenic	Sulfur	Iron	Total admixtures	Designation
Cy0	99.85	0.7	0.04	0.02	0.1	0.02	0.15	Special Batteries
Cy1	99.65	1.0	0.08	0.05	0.1	0.03	0.35	Batteries and type metal alloy
Cy2	99.50	2.0	0.1	0.05	0.1	0.05	0.50	
Cy3	99.40	0.4	0.2	0.25	0.1	0.15	0.60	Babbitts
Cy4	98.80	0.8	0.3	0.25	0.4	0.25	1.20	Solder; Electrotypes

Metallic antimony is governed by additional conditions which limit the content of Zn, Mn, Ni, Bi, Co, Au, Pt, and other metals in hundredths and thousandths of one percent.

In antimony of brands Cy3 and Cy4, used in alloys with copper or lead, the allowable copper or lead content is correspondingly increased to 5%. In brands of antimony used in the manufacture of arsenous babbitts, the allowable arsenic content is increased to 3%. In those cases, the content of the elements named is not considered part of the over-all content of admixtures.

Metallic antimony (regulus) is produced at the plant in the form of ingots.

In addition to standards established for metallic antimony, there are USSR standards for antimonous lead. Brands CCy1, CCy2, and CCy3 are standard designations for antimonous lead and quality requirements are listed in Table 10.

TABLE 10

VARIETIES OF ANTIMONOUS LEAD (IN ACCORDANCE WITH GOST)

Brand	Chemical Composition (in %)						Designation
	Lead and antimony, not less than	Of that, antimony	Admixtures, not more than				
			Tin	Copper	Zinc	Other	
CCy1	99.5	0.3 - 3	0.3	0.3	0.3	0.2	Core alloys
CCy2	99.4	3.0 - 6.0	--	0.3	0.05	0.25	Typecasting
CCy3	98.8	1.0 - 6.0	0.25	0.5	0.25	0.25	Manufacture of dies for diecasting of aluminum alloys; also mixed with lead in lead plating operations

The requirements listed in Table 10 are based on the extraction of antimonous lead through the processing of scrap metal and other materials, without the addition of antimony. The data indicate the requirements for the quality standard desired in antimonous lead which may be obtained from ores mined in various complex lead-antimony deposits.

Trisulfide of antimony (antimonium crudum) is governed by technical specifications TsMTU 996-41, which establish 2 classifications -- CTC-1 and CTC-2 (see Table 11).

Trisulfide of antimony must be in pieces of different size, radiating-crystalline in structure, or it may be in powder form. Reaction of aqueous extraction for brand CTC-1 in terms of methyl orange must not be acid. Admixtures visible to the naked eye are not permissible.

TABLE 11

COMPOSITION OF ANTIMONIUM CRUDUM (IN ACCORDANCE WITH TU)

Chemical composition (in %)

Brand	Antimony not less than	Sulfur	Admixtures: not more than			Moisture
			Sulfur (free)	Trisulfide Residue of arsenic insoluble in aqua regia		
CTC-1	6 - 73	25 - 28.3	0.07	0.7	0.3	0.2
CTC-2	9 - 73	25 - 28.3	0.10	1.0	0.5	Undetermined

Based on technical specifications STU-TaM 901-40, antimonous flotation concentrate must conform to the following: it must contain not less than 33% Sb_2S_3 and not more than 5% moisture. A dried sample quantity must pass through a 100-mesh sieve to the extent of 90%, and to the extent of not less than 60% through a 170-mesh sieve.

The match manufacturing industry uses a concentrate obtained from the first 2 chambers of flotation machines of concentrating plants.

High-grade concentrate is not governed by any specific standards other than that it must have an antimony content of not less than 25%.

Current prices of mercury, antimony, and certain other industrial antimony products are given in Table 12.

TABLE 12

PRICES OF PRODUCTS OF THE USSR MERCURY AND ANTIMONY INDUSTRY

Product	Brand	Price per Ton (rubles)
Mercury	R1	100,000
Mercury	R2	97,600
Mercury	R3	96,000
Antimony	Cy0	32,700
Antimony	Cy1	29,700
Antimony	Cy2	26,000
Antimony	Cy3	20,300
Antimony	Cy4 and CyM	18,000
Antimonous lead	CCy1	3,200
Antimonous lead	CCy2	3,100
Antimonous lead	CCy3	2,800
Trioxide of antimony (very pure)	--	40,000
Antimonium crudum	CTC-1	15,700
Antimonium crudum	CTC-2	14,900
Pentasulfide of antimony	--	59,000
Flotation antimony concentrate (33%)	--	5,000
High-grade antimony concentrate (30%)	--	3,200

Chapter 4. Data on the Technology of Processing Mercury andAntimony OreProcessing of Mercury Ore.

The processing of mercury ore for the purpose of obtaining metallic mercury can be carried out either by means of direct metallurgical conversion or with the aid of the combined method of first concentrating the ore and then putting the concentrate through the metallurgical conversion process. Selection of one or the other approach depends primarily on the composition and quality of the ore. Achievements in the field of mercury metallurgy have made it possible to convert ore with even a low mercury content. If production on a sufficiently large scale can be organized, it is possible to convert mercury ore that has a mercury content of more than 0.1% without first concentrating it.

Metallurgical conversion yields 90% and more of mercury from mercury ore. Thus the need for initial concentration of mercury ore is determined by economic considerations. It must be remembered that if the combined method is used, whereby the ore is first concentrated and then converted, loss of the metal will be considerably greater.

In the case of complex ores the task of extracting the admixtures, primarily the extraction of antimony, requires the use of the combined conversion method.

Direct metallurgical conversion of mercury ores is carried out by dead roasting of coarse ore (pieces 50 mm in size or smaller) at 700 to 800° C. This temperature assures the rapid and complete separation of the cinnabar in accordance with the equation $\text{HgS} + \text{O}_2 = \text{Hg} + \text{SO}_2$. The released mercury in vapor form (its boiling temperature is 357° C) leaves the furnace together with the chimney gas

and is collected in a special condensation apparatus. Several types of furnaces are used for the roasting of mercury ore: pit furnaces of various types; reverberatory furnaces, retort furnaces, multihearth furnaces, and tubular furnaces. The most convenient, economical, and productive modern furnaces are those of the tubular rotating type.

The furnace gases, together with the mercury vapors are sucked by fans through a battery of metallic tubes and are subjected to air, water, or a combined cooling system. In the lower portion of the condensation tubes receptacles are provided in which the metallic mercury and a byproduct, stupp, are collected. Stupp is a mixture of minute drops of mercury and soot, ore dust, mercury oxide, and arsenic. Mercury content in stupp may be as high as 80%.

Completeness of mercury distillation in the roasting process depends on the temperature and duration of roasting. The duration is a variable that depends on the type of ore which is to be roasted. Ores that are porous at the start, or those that become porous during the roasting process, will produce mercury more rapidly than compact ores.

The most harmful admixture in ore, arsenic, hampers the normal course of the metallurgical process. Vapor pressure of trioxide of arsenic reaches 760 mm at 500° C. For this reason trioxide of arsenic is fully sublimated at working furnace temperatures and, precipitating in the condensation system, reduces the collection of mercury, helping to form large quantities of stupp.

Plant personnel must be protected against the toxic action of mercury vapors. Accordingly, most components of the apparatus must be hermetically sealed, particularly the condensation installation.

The processing of relatively small quantities of high-grade ore or of mercury concentrates can be carried out in simply constructed retort furnaces consisting of a series (usually 4 to 6) of iron or pig iron retorts embedded in a muffle furnace. The retorts are loaded with ore at one end which is then closed with a cover; the other end of the retort is connected to the condensation system. Mercury vapor, produced through the heating of the retorts, is directed into the condensation system. Since cinnabar is separated in the retort furnace because of oxygen shortage, the ore or the concentrate mixes with lime. Under these conditions, the following cinnabar separation reaction takes place:



Though their efficiency is not great, retort furnaces, because of their small clearance and light weight, are frequently used for the processing of high-grade ore in relatively small ore deposits located in areas that are difficult to reach.

When the combined method of mercury ore processing is used, the metallurgical cycle is preceded by the mechanical concentration of the ore. This method is particularly applicable in the processing of complex mercury-antimony ores. Such ores, after being crushed, are subjected to flotation, sometimes in conjunction with gravitational concentration in settling machines or on concentration tables. Intensive research and many experiments have so far failed to produce selective mercury and antimony concentrates.

This industry produces collective mercury-antimony concentrates. To obtain mercury, these concentrates are loaded into special retort furnaces. The antimonite remains in the cinders which are then processed to extract antimony.

On the whole, mercury processing plants are small and compact. The establishment of a mercury processing plant of average capacity requires a relatively small area. Such plants require power only for the crushing of the ore, rotation of the furnaces, and operation of the blowers which suck the gases through the condensation system. Masut oil is commonly used as fuel. Depending on local conditions, the fuel expenditure is approximately 28 to 32 kg/t of ore. Use of other types of fuel, such as coal or wood, requires the installation of more complex heating systems. Quantity of water used in a mercury processing plant is also relatively small. When it is necessary to construct a concentration plant, requirements of area, power, and particularly of water increase considerably. The quantity of water required in the mechanical concentration of the ore is normally between 5 and 6 m³/t/ of ore.

Processing of Antimony Ores

In contrast with mercury ores, antimony ores almost always require concentration prior to metallurgical processing. Usually, antimony ores are nonuniform in terms of antimonite content. Frequently found in comparatively poor ingrained ores are pockets and irregular veins of high-grade ore which sometimes contain solid ore minerals. For this reason, the ore is normally sorted. This sorting process which sometimes is carried out right at the pit produces high-grade concentrate which, if it contains 30% or more

of antimony (this corresponds to 42% of antimonite) can serve as a commercial product or can be used in the production of trisulfate of antimony, or can also be used in the smelting of metallic antimony black.

High-grade ores with a content of 8 to 12% may serve as the raw material for the extraction of antimony by use of the metallurgical process. Ordinary ore with an antimony content of less than 8% must first be subjected to mechanical concentration. However, it must be remembered that antimony oxides are extracted in small quantities only. Because of their relative softness, antimony oxides become mixed with the sediment during processes employing the gravitational method of concentration. Nor are very large quantities extracted when the flotation method is used. As for antimonite, it can be floated with excellent results and small losses even if relatively poor ore is used which contains only 0.8 to 1% of antimony. The flotation process is sometimes combined with the gravitational method, the settling and concentration on tables.

If mercury is present in antimony ores, collective mercury-antimony concentrates are obtained. Auriferous pyrites and wolfram minerals (ferberite and scheelite) as well as arsenopyrite can be separated as independent concentrates in the course of the concentration process.

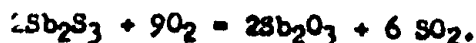
Extraction of antimony reaches 85 to 90% in the case of medium to high-grade sulfide ores (4 to 6% Sb). Extraction normally does not exceed 70 to 75% from the poor-grade ores (1 to 1.8% Sb). Extraction of antimony in concentrate decreases in proportion to the increase in the content of oxide minerals in

antimony ore. reason, it is very important that the extent of the process of oxidized minerals in the ore be carefully studied.

A commercial antimony product is the so-called antimonium crudum -- antimony trisulfide, liquated from sulfide ores. However, in view of the relatively great antimony loss (30 to 50%) in the course of production, and in view of the low price of this product, there has been little production of it in the recent past. Crudum is obtained through heating of antimony concentrates, having a 40 to 50% antimony trisulfide content, to 600 to 700° C in crucible furnaces having a perforated bottom. These furnaces, covered at the top to prevent entry of oxygen and inserted into a second furnace, are placed into a compartment kiln. When a temperature of 548° C is reached, the antimony trisulfide is melted and flows into the lower furnace. The cinders normally contain 15 to 20% of antimony.

The oxidizing roasting with sublimation is a very interesting metallurgical process whose end product is trisulfide of antimony. The latter, as is known, is volatile and when heated even to a temperature below its melting point (656° C) is sublimated. Useful admixtures such as gold or silver can be extracted from the cinders. This method is of particular interest in the processing of ores that contain considerable quantities of antimony in oxidized form.

During the roasting which is carried out at a temperature in excess of 400° C, the natural trioxide of antimony contained in the ore is sublimated immediately, while the antimony trisulfide is sublimated only after initial oxidation in accordance with:



To transform the nonvolatile Sb_2O_4 into Sb_2O_3 , the necessary conditions must be created in the furnace through the use of reducing agents.

To separate volatile trioxide, the furnace gases are cooled and subsequently purified in a series of devices capable of collecting 98 to 99% of the antimony trioxide contained in the gases.

Metallic antimony is obtained from plant concentrates or high-grade ores through the so-called process of settlement smelting with iron in reverberatory furnaces at temperatures ranging from 1200 to 1300° C. This process is carried out in accordance with the reaction:



Antimony, the heavier element, is collected at the bottom of the furnace, while the sulfurous iron becomes part of the matte. Fusing agents, such as soda or sodium sulfate are used to form slag of the waste material, while coal is used to reduce the oxides. The product obtained through this process is the so-called black, or grey, antimony, containing from 6 to 15% iron.

Black antimony is further refined in a second smelting process during which measured quantities of crudum or high-grade antimony concentrates are added in order to transform the iron in accordance with the above reaction into sulfurous iron and transferring it into the matte. In the course of the settling-smelting process the admixtures of arsenic, lead, gold, and silver pass into the antimony. The latter 3 metals can be removed only through electrolysis. The removal of the arsenic, a particularly harmful admixture of antimony, is achieved through refining by smelting of black antimony under addition of soda or potassium.

Up to 80% of antimony passes into the crude metal, while up to 9% of antimony remains in the matte, and up to 15% escapes in the form of trioxide. For this reason, in order to collect the antimony trioxide, all furnace gases must be channelled through a dust-collecting system.

To obtain the metal, antimony trioxide is reduced in a reverberatory furnace. Antimony trioxide, frequently having a metal content of up to 75%, is mixed with a reducing agent (coal or charcoal) and with fusing agents (calcined soda or sodium sulfate). Loss of antimony in the reduction process ranges between 5 and 20%. The slag which is enriched with antimony is, in turn, subjected to processing. In the reduction smelting of high-grade ores, the admixtures such as gold, silver, or lead all pass into the antimony.

Hydrometallurgical methods of ore processing are based on the fact that antimony trisulfide is easily soluble in relatively weak solutions of sodium sulfide. Subsequent electrolysis of the antimony produces a metal of exceptional purity (brand CyQ).

The system of processing antimony ores is greatly more complex than methods used in the processing of mercury. As a rule, any processing of antimony must be preceded by a concentration operation carried out in a concentration or metallurgical plant. Such an installation is quite complex and costly and is economic only when adequate supplies of raw material can be counted on.

The extraction of the commercial metal, if losses of 5 to 10% are taken into consideration, can yield from 80 to 85% mercury, while only 40 to 60% of antimony can be extracted from known deposits.

MERCURY AND ANTIMONY DEPOSITS IN THE USSR

Prior to the Great October Revolution the antimony industry was nonexistent in Russia. Mercury was extracted in comparatively limited quantities -- these only at the Nikitovka deposit in the Donets Basin -- unless one counts some minor efforts to exploit the Il'dikanka deposit in Transbaikalia at the end of the past century and the Khpeka deposit in Dagestan early in the present century. Knowledge of Russia's mercury and antimony deposits in general at that time was extremely scanty.

At a number of places in Russia, however -- in the Donets Basin, in Ruthenia, and particularly in Central Asia -- a fairly well developed mercury industry had existed in the ninth to the twelfth centuries, traces of which have survived in the form of numerous ancient excavations, the remains of metallurgical furnaces, ceramic tiles and condensation pipes, stone hammers, iron chisels, and piles of candleends. Traces of this ancient industry serve today as one rather important indication during prospecting for mercury deposits.

Geological prospecting and exploration conducted by Soviet geologists have led to the discovery of quite a number of antimony and mercury deposits in various regions of the USSR. Of course these deposits represent by no means all the potential antimony and mercury resources of the USSR. The discovery of new deposits of these metals continues to be a most important task for Soviet geologists.

Geological Position of Deposits

Deposits and ore outcroppings of mercury and antimony in the USSR are rather widely scattered; they occur in Ruthenia, in the Donets Basin, in the Caucasus (on the northern and southern slopes of the main range), in Central Asia, in various parts of Kazakhstan, in Gorno-Altay, in the Kuznets Ala-Tau, in Transbaikalia, in the Maritime Territory, and in the Urals. A study of the pattern of the USSR's mercury and antimony ore deposits shows that these 2 metals are consistent components of a general hydrothermal process of ore formation. The conditions under which mercury and antimony are deposited, however, differ sharply from the conditions of deposit for other metals.

It is at once evident that large deposits of mercury and antimony are formed in ore-bearing regions where strata of sedimentary rock overlying a hard crystalline base -- strata which make up the various formations -- have a great but variable thickness.

In the Donets Basin, for instance, the mercury ore vein lies in a thick (2,400-5,400 m) Middle Carboniferous stratum of mixed shale-sandstone-limestone composition, which is underlain by a stratum of Namurian and Upper Viséan sandy shale of analogous composition (up to 2,400 m) and by Viséan and Turonian limestone (216-455 m). The latter lie either directly on a Pre-Cambrian crystalline base or, in some places, on Devonian continental or oceanic sediments up to 600 m thick.

The ore-bearing Middle Carboniferous is in turn covered by shales and sandstones of the Upper Carboniferous (2,100-2,800 m). The sandy, gypsum-dolomite and salt-bearing strata of the Permian, which overlie the Carboniferous in the northeastern part of the Donets Basin, are characterized by considerable variation in thickness (1,700 to 3,700 m). Like the Meso-Cenozoic sediments, they are absent in the region where ores are most plentiful.

In the Caucasus the mercury and antimony deposits on the northern (Dagestan) and southern (Georgia) slopes of the main range lie chiefly in Jurassic strata which cover ancient crystalline rocks. The thickness of these Jurassic strata reaches 4900 m. The Jurassic deposits, like the Chalk and Paleogene, which overlie them in adjacent regions (up to 4700 m in thickness), have a Flysch character, 79% being terrigenous deposits and 21% carbonaceous.

Mercury deposits in the Stavropol' Territory are associated with Permian sandstone-conglomerate strata. Here too the crystalline base lies at considerable depth -- more than 2000 m.

In Central Asia the geological conditions under which mercury and antimony deposits are found are extremely varied. In the Kopet-Dag they are associated with the middle portion of the Lower Chalk, whose total thickness reaches 2000 m. Here the lower 500 to 700 m are composed of Barremian limestone and the upper 1300 m of clayey-sandstone rocks of the Aptian and Albian. Apparently lying below the lower Chalk in the Kopet-Dag are Jurassic strata with a thickness of 2,000 m. Thus, here too, the crystalline base lies at extremely great depth.

In the southern part of the Tien Shan, mercury and antimony deposits are most frequently associated with Carboniferous strata represented by alternating layers of limestone and shale with a total thickness of 500 to 1,500 or 2,000 m; these are underlain by Devonian, Upper Silurian and Cambrian strata, partly terrigenous and partly of limestone composition, quite variable but on the whole quite thick. The Pre-Cambrian base is most probably crystalline in character. At certain places in the Tien Shan, mercury and antimony deposits are also encountered in Silurian and Devonian strata, but only where the latter's thickness is markedly greater.

In the northern ranges of the Tien Shan there are scattered deposits lying in the upper portions of a very thick and ancient stratum of metamorphosed shale and marble, possibly of Proterozoic age. Mercury and antimony mineralization is also encountered in effusive-terrigenous strata of the Carboniferous and Permian, which overlie either the afore-mentioned Proterozoic shales and marbles or Silurian and Devonian strata.

In Altai and Western Siberia, mercury and antimony ores are found in very thick Middle and Lower Paleozoic strata of mixed composition; these border the Kuznets coal basin on the east (Kuznets Ala-Tau) and west (Salair) and extend farther south into Gorno-Altay.

In the Krasnoyarsk Territory antimony deposits lie in extremely thick sedimentary strata of the Pre-Cambrian and Cambrian.

In the Maritime Territory mercury and antimony ores are found in Upper Paleozoic and Jurassic strata, i. e., quite far above the crystalline base.

While the total thickness of the sedimentary rocks with which the Soviet Union's mercury and antimony deposits are associated is very great, considerable variation in the thickness of the individual formations which go to make them up is quite characteristic. From all the foregoing, one may draw the significant conclusion that mercury and antimony deposits are formed in regions which have experienced great, complex, and often differentiated tectonic movements. Formation of the deposits is associated with the final phase of these tectonic movements.

The great thickness and lithological complexity of sedimentary strata determine how solutions evolve as they move along their course and to what degree they become differentiated.

It is also significant to note that in cases where conditions favorable for ore accumulation are also manifest in ore-bearing strata -- conditions such as those which will be discussed below -- deposits are sometimes found at several levels or layers (Central Asia, Donets Basin).

Let us now examine the question of tectonic control of the location of deposits.

In most cases the mercury and antimony deposits of the USSR lie in long, narrow zones, sometimes extending hundreds of kilometers. As detailed research has shown, such distribution of mercury and antimony ores is due to the fact that they are formed along large, complex zones of crust movement, usually between a depressed area and an uplifted area.

Of this type, for instance, are the fault zones controlling the location of deposits observed along the edges of the Sur'metash and Karachaty Upper Paleozoic depressed areas in the Alay Range of Central Asia, as well as the faults bordering the Kusnets Depression in Western Siberia. In the Caucasus, mercury and antimony deposits are also distributed along faults marking the contours of depressions in which have accumulated extremely thick strata of Meso-Cenozoic Flysch sediments.

Unfortunately, such an analysis of the geological-tectonic position of mercury and antimony deposits has not as yet been made for many of the mercury-antimony regions of the Soviet Union. In the Donets Basin, for example, the geological position of the ore-controlling fissures is still not clear. They may be linked with the outlines of depressions of Permian age. But for the principal mercury and antimony ore regions of the USSR, it may be considered a proven fact that the distribution of deposits is controlled by deep faults which have clear and diverse geological manifestation and which conform to the over-all geological structure.

Enduring Rocks, their Age and Composition

The rocks in which mercury and antimony deposits lie are rather varied both as to composition and as to age. They include conglomerates, sandstones, shales, limestones, intrusive igneous rocks, and agglomerated effusive and tuffaceous rocks of volcanic origin.

The age of these rocks ranges from Pre-Cambrian to Upper Miocene. Of course the upper age limit of ore-bearing rocks in each individual region is determined by the period in which the formation of the deposit took place.

For example, in the Tien Shan the age of most of the mercury and antimony deposits is Permian. Consequently, the deposits in this area are found, where conditions are correspondingly favorable, in rocks of any age in the older Permian -- in the Carboniferous, the Devonian, the Silurian, and even in the Cambrian and Pre-Cambrian. But for the several regions in Central Asia, depending on their geologic history, other ages of mercury mineralization are sometimes observed: Post-Jurassic for the Kugitang-Tau, Post-Chalk for the Kopet-Dag, Middle and Upper Carboniferous for the Talass Ala-Tau, etc. All this is appropriately taken into account when prospecting operations are being organized.

As far as rock composition is concerned, the USSR's largest mercury and antimony deposits are associated at times with rocks having a considerable primary porosity (porous sandstones, conglomerates) and for the most part with brittle rocks which under tectonic deformation can form brecciation zones containing a large number of empty spaces (limestones, sandstones, quartzites). An extremely important condition (observed in all industrial deposits of the Soviet Union) for the formation of large concentrations of mercury and antimony minerals in areas of high primary or secondary porosity is that these areas be of a relatively isolated character, with a covering of compact, impermeable rocks -- usually clays and shales.

Structural Characteristics of Deposits

As a rule, mercury and antimony deposits in the Soviet Union's ore regions are formed in sectors which are quite broken up tectonically. This follows logically from their location, as noted above, in zones of transition between depressed areas and

upthrust areas. Such zones are usually characterized by very complex structural forms due to both folding and faulting of the earth's crust. This accounts for the extreme diversity of structural forms bearing ore deposits.

First of all, we should discuss deposits which are in the form of a layer or bed, then those orebodies which are irregular in shape and have resulted from massive brecciation of the rocks, and finally ore veins of many different forms, often very complex. In all deposits of these structural types 3 common structural features are observed: (1) channels of access, which take the form either of well-defined fissures and cracks, individual or in series, or of zones of intensive fine fissuring in the rock; (2) ore-accumulating cavities, usually linked with the channels of access through offshoots rather than directly; and (3) a layer of impermeable rocks lying over the ore-accumulating cavity.

The channels of access determine the location of deposits within the limits of ore belts and zones, but they themselves often remain virtually unmineralized, since their great extent usually gives them a through-passageway character. Ore-bearing solutions have apparently been brought to the surface through them without forming any ore concentrations (Central Asia; Caucasus, Altay, Donets Basin).

The character and shape of the ore-accumulating cavities naturally determine the shape of the deposits. The latter may be layer-shaped, in the form of a saddle or mould, associated with corresponding folds of the enclosing rocks (Central Asia, Donets Basin); layers of porous rock associated with denser rocks in a monocline (Central Asia); or various types of bedded deposits

lying between strata of rock which differ lithologically from each other, both sedimentary and igneous (Ruthenia). Especially noteworthy are the irregularly-shaped ore-bodies due to massive brecciation of brittle rocks; these usually extend to the heart of tightly pressed folds (Central Asia). Ore veins are usually associated with fissures due to faulting or, less frequently, to cleavage.

Mercury and antimony ore veins often intersect more or less rigid, brittle rocks, attenuating in the softer, more plastic rocks above them (Central Asia: limestone under shale; Altay: limestone and sandstone under shale and serpentine; Kazakhstan: sandstone under shale; Donets Basin: layers of sandstone and quartzite in shale). A number of antimony ore crack-veins in Kazakhstan, the Caucasus, and the Chita Oblast even lie in intrusive igneous rocks which have penetrated sedimentary strata. They quickly attenuate and break down in the latter. There are some veins, however, which intersect even rather plastic rocks -- Jurassic shales in the Caucasus, metamorphic Pre-Cambrian shales in the Krasnoyarsk Territory, etc. But even for these veins, isolation from above is characteristic, as is shown by their enclosed offshoots and apophyses, which as a rule are noteworthy for higher-quality ore, and by independent blind-alley veins, always richer at their upper ends. It should be pointed out that veins associated with relatively plastic rocks are characterized by intermittency and often form lenticular pockets, single or in series (Caucasus, Krasnoyarsk Territory).

Mercury and antimony deposits of the layer type are of the greatest importance for practical purposes.

Figures 10, 11, 12, 13, and 14 show the most important and typical structural forms of mercury and antimony deposits in the USSR.

Material Composition of Deposits

The Soviet Union's mercury and antimony deposits are rather varied in material composition and range from virtually single-mineral deposits of cinnabar and stibnite to extremely mixed, complex, multimineral deposits.

Quartz is of the greatest importance as a gangue mineral. Intensive quartz formation is very often observed in mercury and antimony deposits; it takes the form of metasomatic replacement of the rock by fine-crystalline quartz, often peratoid in structure, or sometimes by chalcedony. But as a rule this quartz formation always precedes ore deposition. First-generation quartz generally cements fragments of rock. In addition, second-generation quartz is often observed; this is nearer in time of origin to the time of the ore-deposition process itself, and sometimes almost simultaneous with it. Second-generation quartz most frequently forms well-defined grains of columnar, prismatic crystals which grow in druses in the cavities.

These zones of quartz formation, which stand out sharply in relief and which are covered with a dark crust of desert tan when climatic conditions are favorable, are an important indication in prospecting for mercury and antimony deposits. It must be kept in mind, however, that such quartz zones are not always accompanied by orebodies, even in regions known to contain mercury and antimony ores.

Besides quartz, some Central Asian and Maritime Territory deposits contain fluorite, whose possible importance as a useful by-product must be considered. Another common gangue mineral, especially in deposits which were formed in a carbonaceous environment, is calcite. Complex carbonates and barite are less frequently encountered in mercury and antimony deposits. Still, in Central Asia there are some known mercury deposits with barite and ankerite as the principal gangue mineral.

Although quartzless antimony deposits or orebodies are a great rarity, quartzless mercury deposits with calcite or, less often, dolomite as the principal gangue mineral are often encountered, especially in carbonaceous rocks.

In the USSR's mercury and antimony deposits the following hypogenic ore-bearing minerals (listed in the approximate order of their frequency and typicality) are found:

In Mercury Deposits [1]	In Antimony Deposits [2]
Cinnabar	Stibnite
Metacinnabarite (Usually metacinnabarite is a secondary mineral in mercury deposits, but some researchers nevertheless admit the possibility that it is of hypogenic origin.)	Pyrite
	Cinnabar
	Boulangerite
	Bournonite
	Jamesonite
	Sphalerite
Pyrite	Marcasite
Stibnite	Chalcopyrite
Realgar	Galena
Orpiment	Gold

[1]

Marcasite
 Selenium-bearing varieties
 of cinnabar
 Schwazite
 Famatinite
 Chalcopyrite
 Galena
 Sphalerite
 Gold
 Hematite
 Bismuth glance

[2]

Arsenopyrite
 Berthierite
 Realgar
 Orpiment
 Pyrrhotite
 Famatinite
 Hematite
 Magnetite
 Wolfram (ferberite)
 Silver
 Bismuth glance
 Stannite
 Titanite
 Schselite

From the list of minerals above, certain differences are apparent between the material composition of mercury deposits and that of antimony deposits; for instance, antimony deposits contain a greater number of minerals which occur in ore deposits of other metals.

It is curious to note that while galena is sometimes found in mercury deposits, lead in antimony deposits more often forms sulfo-salts containing antimony, and only rarely is lead found in the form of galena. Stibnite is virtually never found in deposits where lead is present. In the latter antimony is encountered chiefly as a component of sulfo-salts, or very infrequently in the form of native antimony.

The above list of hypogenic ore-bearing minerals in both mercury and antimony deposits bears witness to the genetic relationships between mercury and antimony oreformation and other types of mineralization [see Note.] These relationships become still more apparent if one considers the complex polymetallic deposits which contain antimony-bearing tetrahedrite and the presence of antimony in considerable quantities in some gold and gold-polymetallic deposits.

([Note:] The author is attempting to prove that mercury and antimony deposits originate from the same solutions which first lay down gold, lead, and other polymetallic ores. The proof, however, is not very convincing, since the small quantities of lead in mercury and antimony deposits may have been absorbed from the wall rocks. Furthermore, the idea is not verified geologically. As a rule, no locally widespread connection is observed between polymetallic deposits and deposits of mercury and antimony. -- Editor's note.)

These genetic links between the processes forming mercury and antimony deposits, and those forming other types of ore deposits, are also indicated by the fact that the material composition of mercury and antimony deposits depends on their geological position. This has been demonstrated by comparing such deposits in various ore regions of the Soviet Union.

It appears, for example, that single-mineral mercury deposits, evidently formed by well-differentiated solutions, are located in the upper portions of the thickest and most lithologically complex strata. On the other hand, deposits associated with strata which are not so thick and are underlain

by rigid, brittle, and consequently more penetrable rocks, often have a mixed, complex mineral composition; i. e., they were formed by nondifferentiated solutions. In other words, the composition of ore-bearing solutions is observed to undergo a definite evolutionary change in the course of their movement through thick, complex rock strata.

A very interesting question which has not yet been pursued very far is that of the paragenetic relationships between minerals in the mercury and antimony deposits of the USSR. Nevertheless, the factual data at hand indicates that the process of ore formation may be considered a very protracted and consistent one which develops according to definite principles. The composite paragenetic diagrams in Figure 15 show this rather clearly. They are derived from data from mineralogical study of a number of Central Asian mercury and antimony deposits. From these diagrams it is evident that if the precipitation of certain minerals or their derivatives in individual deposits be disregarded, the general course of development of the mineral deposition process is a fairly consistent one.

Relation to Igneous Rocks

The intrusive or effusive igneous rocks, near or within which certain mercury and antimony deposits of the Soviet Union lie, of course cannot be considered the source of the ore-bearing solutions involved. Geological correlation nearly always shows convincingly that they are of considerably greater age than the deposits themselves.

A number of mercury and antimony deposits have been formed at depths of 1,000 to 2,000 m, and mercury mineralization covering a great span along the vertical (1,300 m and more) without any substantial change in its material composition has been observed in certain mineral regions of Central Asia. These facts oblige us to place the sources of the ore solutions at relatively greater depths. The intrusion of pre-ore, ultrabasic rocks to form stocks and dikes along certain great ore-controlling faults (Central Asia) also points indirectly to the possibility that the source of ore-bearing solutions lies at considerable depth.

On the other hand, it is noteworthy that the igneous rocks, containing mercury and antimony deposits in the Soviet Union's ore regions (the Alay, Turkestan, Hissar, and Talass Ranges of Central Asia, the Donets Basin, the Urals, Altai, etc) are alkaline in character. Also typical is the presence in these areas of ultra-alkaline igneous rocks (nephelitic syenite, barkevikite, shonkinite, etc) accompanied by a great many minerals containing fluorine; these are characteristic of many mercury and antimony regions, particularly in Central Asia.

However, numerous attempts to attribute the origin of mercury and antimony deposits to this or that type of magmatic rock have led to no results of practical or theoretical value.

FIGURES

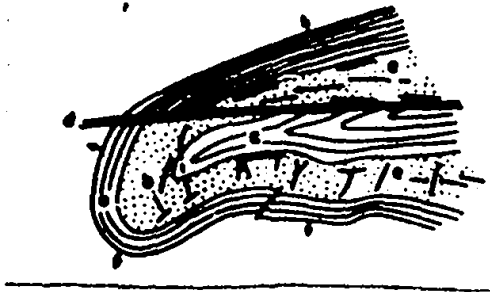


Figure 10

Plan view of the periclinal end of an ore-bearing anticline. a, overlying shale; b, ore-bearing sandstone; c, underlying shale; d, fault; e, ore-veins with cinnabar

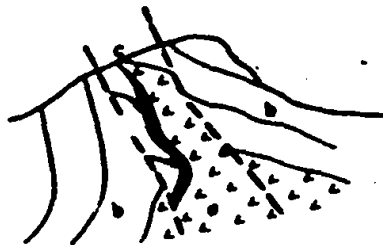


Figure 11

Cross section of a mercury deposit association with the contact of a serpentinized intrusion of hyperbasite. a, hyperbasite; b, sedimentary-effusive strata; c, ore deposit

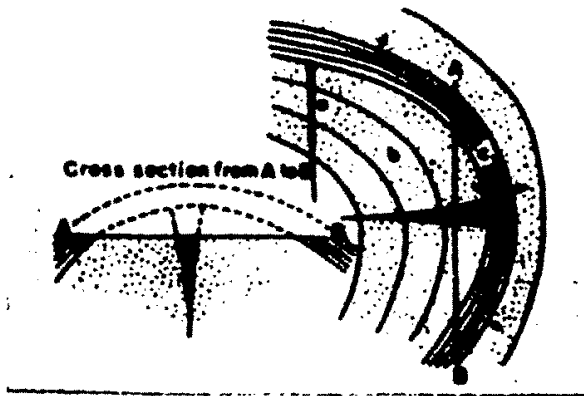


Figure 12

Plan view and cross section of an antimony deposit associated with radial cracking in a dome. Ore veins (a) in the sandstone forming the heart of the fold (b) extend only as far as the level of the shale (c), whose ore-controlling significance is thus readily apparent



Figure 13

An antimony ore-vein (a) associated with a fault crack in metamorphic shale (b). The richest ore (in black) is concentrated in the dead ore-shoots branching off from the vein and in the wide spaces in vein

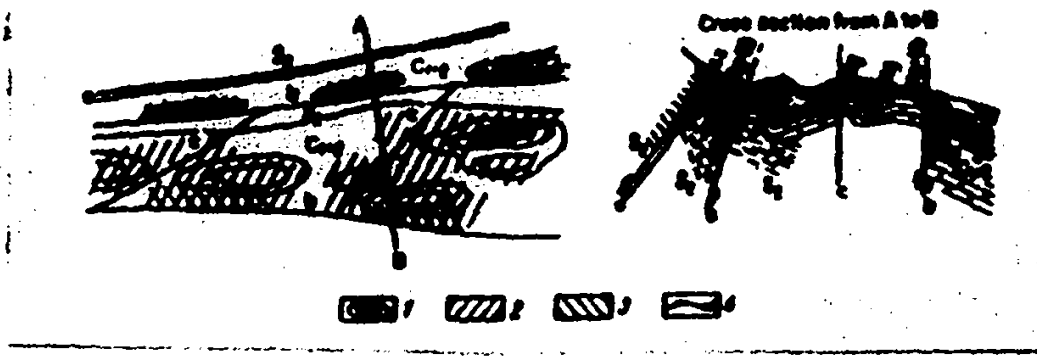


Figure 14

Structural diagram of a whole mercury-antimony ore field. a, the great slippage which has caused the peculiarities of folded structure; b, ore-controlling fissures; c, ore-distributing fissures associated with the latter, intersecting an upthrust block. 1, anticlinal folds; 2, mercury ore; 3, antimony ore; 4, ore deposits

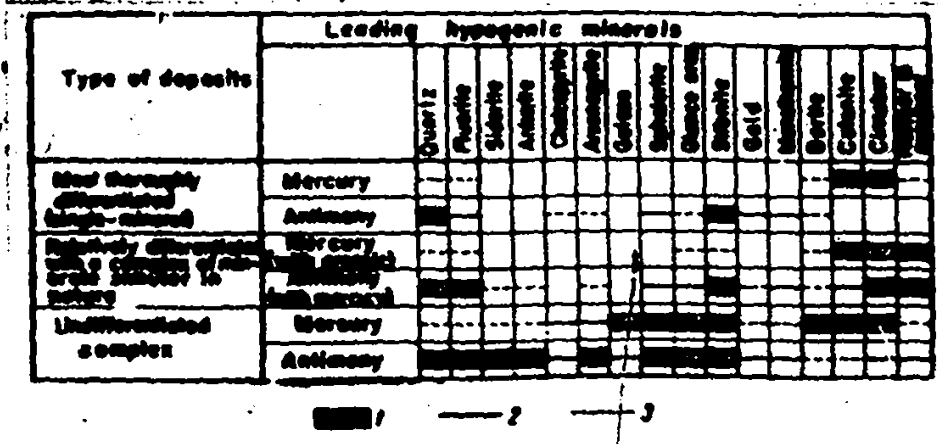


Figure 15

Paragenetic diagrams for typical kinds of mercury and antimony deposits of Central Asia; 1, much; 2, considerable quantity; 3, little